

Sound Structure and Directionality in *Orcinus* (killer whale)

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(Figures 1-5)

INTRODUCTION

Orcinus orca (Linné) 1758, the killer whale, has long been noticed and spoken of under a wide variety of vernacular and technical names. For all the attention devoted to it, very little has been noted, or at any rate recorded, of its phonation (or sound production). Grieg (1907) describing the trapping and killing of 47 killers, mentioned what he called flute-like sounds from the young and roars from the old bulls. Valdez (1961) described killer whale clicks as heard by ear through the hull and as recorded on an echo-sounder in the first published reference to hearing this species under water. Schevill (1964, p. 313) listed unpublished recordings by the Royal Canadian Navy (made in June, 1956, along the west coast of the Queen Charlotte Islands and on February 19, 1958, in Saanich Inlet, Vancouver Island, B. C.) and by the United States Navy (on October 20, 1960, in Dabob Bay, Hood Canal, Washington). As far as we know, these are the only recordings made before the capture of the Vancouver killer, which was harpooned in the Strait of Georgia July 16, 1964 (Newman 1964, 1964a). The underwater calls of this young bull were recorded by Dr. Patrick L. McGeer of the University of British Columbia and by us (this study). Mr. Gerald Kooyman of the University of Arizona has generously given us some of his *Orcinus* recordings of January, 1965, in McMurdo Sound, Ross Sea. The present study is based on our own tapes, although we have had the benefit of comparison with those just listed. The captivity of Mr. Ted Griffin's Namu-Seattle *Orcinus* in 1965 has led to a great deal of recording by several workers, not reported at the time of writing.

MATERIAL AND METHODS

Our records were made from August 16 to 18, 1964, on our portable Rowboat Recorder (Watkins, 1963), which has a flat response from 30 cps to 30 kcps. Our subject was the young bull *Orcinus* at Vancouver, British Columbia, captured a month before (Newman, 1964, 1964a). At its death after 12 weeks of captivity, this animal was 4.67 m long and weighed 1,034 kg. The pen in which it was confined was cut out of an old wharf and measured about 14 by 23 m, with a water depth from 3 to 7.5 m, depending on the tide. The water was chiefly Fraser River outflow of very low salinity and high turbidity. Since the sides of the pen were of coarse wire mesh and the water was simply part of the bay, in which there was very little traffic, the acoustic conditions were far and away superior to the tanks in which captive cetaceans are usually confined. Not only were we free of the noises of pumps and land traffic, but the coarse mesh sides did not return the troublesome echoes of the usual tanks. Especially at night, when the bay traffic virtually ceased, we had listening conditions approaching the best at sea.

PHONATION AND CONCOMITANT BEHAVIOR

A striking feature of this whale's phonation was the total absence of the familiar delphinid whistle-like squeal. All the sounds recorded were clicks, or composed of clicks, which themselves were unlike those of typical delphinids. When these clicks were repeated sufficiently slowly, they were individually recognizable (Figs. 3-5); when the repetition-rate was greatly increased, the effect was strikingly different (Fig. 2): a strident scream resulted, often quite loud (we estimate more than 60 db re 1 dyne/cm² at 1 m from the source). Because of the rapid click-rate (too rapid to show much more than the

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sharp front characteristic of separate clicks), these screams are rich in harmonics. As noted further on, it is our impression that these strident screams are used for communication (calling), while the separate clicks appear to be used like the more familiar delphinid click (as in *Tursiops truncatus*, for example), apparently in echolocation.

The whale's habitual circuit of its pen was counterclockwise at speeds of 2 to 4 knots, the loop usually taking 35 seconds. It often blew (respired) once a circuit, but sometimes made two or three circuits on one breath. This routine seemed to be interrupted only at times of calling. (The whale had not then begun to accept hand-feeding.)

The calling appeared to be stimulated by the passing of small boats and occurred both by day and especially by night. During the 3 to 5 minute calling periods, the whale sometimes slowed its swimming or executed smaller circles, often near the gate. The strident screams were consistently loud enough to be heard plainly in air. There would be 30 to 50 of these screams, each lasting usually less than a second and separated one second or more, the spacing increasing until the last calls might be 15 to 30 seconds apart. The final two to five calls ordinarily were longer, lasting as much as 3 seconds. During these calling periods there were very few or no slow clicks between the screams, as if to reduce local interference in favor of careful listening.

During daylight the whale was silent except for infrequent screams, but at night each circuit of the enclosure was accompanied by either steady clicking (2 to 6 per second) or by bursts of slow clicks, a few seconds only between bursts.

We had the following hints that the clicks were used in echolocation. The hydrophone with its preamplifier case (greatest dimensions 4 × 30 cm) was maneuvered into the whale's path by means of an overhead line. During clicking periods at night the whale never touched the hydrophone or the cable above. But during nocturnal calling periods when the whale circled without clicking, it collided with the hydrophone every time the unit was in its way. There were no exceptions—when clicking, the whale avoided all contact with the hydrophone, but when no clicks were heard from the whale a collision could be arranged. Usually immediately following such a collision, the whale would click for a short period. The whale never hit the hydrophone more than once in the same spot; if the hydrophone was left in the same position, no other collisions were noted on successive circuits, even though no clicks were heard.

The whale easily avoided the hydrophone dur-

ing daylight without clicking. Probably this was simply because it could see.

CLICKS

The clicks of other delphinids typically are broad-band (for example, Lilly, 1962, fig. 3; Evans & Prescott, 1962, Pl. 1; Schevill & Watkins, 1962, various figs.). Those of *Orcinus*, on the other hand, have discrete and rather low frequencies for main components, somewhat like those of certain seals (Schevill, Watkins, & Ray, 1963). The *Orcinus* click has a short enough rise-time to give this pulse many high frequency components as well, but at lower amplitudes. The main part of the click is narrow-band and has predominant frequencies with a decaying amplitude (Fig. 1). The click duration is between 10 and 25 milliseconds, depending on its amplitude above ambient. The duration of the click, the restricted frequency emphasis, and the decaying amplitude of the pulse point to a resonance in the click-making mechanism. The fundamental frequency of these click-pulses (the resonant frequency) varied between 250 and 500 cps.

The fundamental frequency of clicks in a group may vary from one click to the next. Characteristically, the clicks were emitted in short bursts, 10 to 15 clicks in each burst, with the first clicks at both a faster repetition-rate and a slightly higher frequency emphasis. A typical burst of 12 clicks starts with a repetition-rate of 18 clicks per second with a 500 cps fundamental frequency, and ends with a repetition-rate of 6 clicks per second with a frequency of 350 cps. Slow click repetition-rates appear to be characteristic of the species.

SCREAMS

Much variation is evident in the killer whale recordings known to us, but certain patterns appear to fit them all. The screams of *Orcinus* are characterized (1) by a strident quality resulting from the strong harmonic structure, indicating that these calls are pulsed, (2) by being generally of two parts, and (3) by each part having a lingering dominant repetition-rate frequency which is generally relatively low, about 500 and 2,000 cps.

On spectrographic as well as oscilloscopic analysis, *Orcinus* screams are seen to be composed of rapid pulses. In spectrographic presentations this is often indicated by the presence of many strong harmonics (for a detailed examination of this phenomenon, see Watkins, in press). These harmonics are largely the product of the pulse repetition-rate, which may be read directly from the harmonic interval, and it is they

that account for the very strident quality of these screams. This structure with many strong harmonics indicates that it is composed of relatively short-rise-time pulses containing many frequencies; these pulses, when produced slowly enough to be separated, are not unlike the slower *Orcinus* echolocation clicks discussed above. Indeed, many screams start with relatively slow clicks whose repetition-rate is increased until the rate of the scream fundamental is reached (Fig. 2). Other screams end with a decreasing pulse repetition-rate, which continues slowing until the clicks may be easily separated. Occasionally, a slow burst of clicks may be increased in repetition-rate until it ends in the typical strident scream and vice versa. At no time were the slow clicks and the screams produced concurrently by our solitary animal, (as has been noted for clicks and squeals in *Tursiops* (Lilly & Miller, 1961) and other delphinids). The clicks do not appear to change much in frequency-composition at increased repetition-rates, but in the scream, when clicks are produced too rapidly to be separate, the repetition-rate harmonic structure is dominant and masks most individual click components. It appears likely that the screams are made by the same mechanism that produces the clicks. This hypothesis is strengthened by our strong impression that they had the same frequency and sound field characteristics, relative to the physical orientation of the animal, as were noted in the echolocation clicks.

Two-part screams appeared to be favored by the captive *Orcinus*, each part having a different predominant repetition-rate frequency. This whale appeared to have preferred 500 cps and 2,000 cps. It hit these notes again and again. A typical scream began with a rapid rise in repetition-rate frequency until 500 cps was reached; then that note was held for the first half of the call, and following another sliding shift in repetition-rate frequency, 2,000 was held. A scream may also have the 2,000-cps part at the beginning with the second part at 500 cps. The end could be another shift, either up or down, or it could trail off at that note. A long call could have as many as five alternations. The subtleties of beginnings and endings of screams could be lost quickly at a distance because of their relatively low amplitude.

The duration of the screams was generally a little less than one second. Calls from 0.1 to 3.0 seconds long have been noted, with 0.65 seconds as the average length.

SOUND PROJECTION PATTERN

The frequency content and amplitude of the clicks produced by the Vancouver captive varied

strikingly with the orientation of the animal. When the whale faced the hydrophone the high frequency components of the clicks were clearly audible, but as the whale turned, these high frequencies diminished progressively (Fig. 3) until only the lowest click components could be heard behind it. Even the low frequency parts of the clicks were harder to hear when the whale was headed away from the hydrophone, indicating that the total sound field also varied with orientation. The clicks were fairly low level. With the animal facing the hydrophone, the clicks were estimated to be only -10 to -20 db at one meter, relative to one dyne per cm², and were often less than 10 db above ambient at one meter. Thus the whale's clicking at times could not be heard until it was quite close and closing range. The intensity of the clicks would increase as the whale approached, and as it turned to avoid the hydrophone it presented the duller areas of its sound projection pattern. The high frequency content of the clicks thus tended to increase as the clicks became louder and then decrease as the whale turned away from the hydrophone. Nevertheless, the low frequency components became progressively louder as the animal came closer (Figs. 4A & 4B). Depending on the amplitude of the signal, it was possible to lose all harmonics and retain only the click fundamental as the animal went past (Fig. 5).

It was impossible to keep exact track of the whale's orientation as it circled the enclosure at night, but the dim yard lights of the adjacent compound and the rippled surface of the water as the whale's fin passed beneath, together with the animal's periodic surfacing, helped give an impression of its position. On a few fortunate occasions, the whale circled virtually at the surface all the way, giving a good check on previous observations. It was possible to correlate click quality (relative presence of high frequencies) and intensity with the location and orientation of the whale.

A 20° shift in orientation from directly ahead gave a detectable difference in the quality of the click to the human ear. A 90° orientation change reduced the intensity of the 3 to 4 kcps components in the signal by an estimated 4 to 6 db. This was sufficient to cause the apparent loss of all harmonics during constant amplitude analyses of low level clicks. At close quarters and directly ahead of the whale there was energy to above 20 kcps, but at a distance and off to the side the fundamental of the click was all that was heard. No high frequency emphasis was noted within the 30 kcps bandwidth of these recordings. A broader bandwidth recording system might have detected higher

frequency components in the head-on sound cone, since these pulses evidently have a very short rise-time.

The idea that odontocetes have a definite and functional sound projection pattern has slowly been growing. Norris, Prescott, Asa-Dorian & Perkins (1961) noted that 100 kcps components of the clicks of *Tursiops truncatus* were received only when the porpoise pointed its rostrum directly at a sharply tuned hydrophone. The authors postulated (p. 172) that "the degree of directionality may vary systematically with frequency." Lilly (1962, p. 523) repeats the observation of the narrow forward 100 kcps beam. Evans & Prescott (1962) described the broad-band sound pressure pattern received through severed heads of *Tursiops truncatus* and *Stenella graffmani* as being markedly stronger ahead and to the right side. Norris (1964, p. 327) predicted that "it seems likely that such asymmetry will be found to extend to frequency and harmonic composition as well."

Evans, Sutherland & Beil (1964) argued that these directional characteristics could result simply from the physical shape of the skull of these animals. Their measurements, made on another species of *Stenella* and a skull of *Tursiops truncatus*, showed a varying sound field with respect to the orientation of the head at any one frequency and an appreciable attenuation at 50 and 70 kcps downward and to the rear. Romanenko, Tomilin & Artemenko (1965), in a similar experiment with both a head and bare skull of *Delphinus delphis*, showed (their Fig. 2) the horizontal sound field for nine frequencies from 10 to 180 kcps. Their plots are similar, but with asymmetry to different sides at different frequencies, and their patterns are sharper.

While the shape of the upper forward surface of the skull may be a reflector (Norris, 1964), the mere obstructive presence of the skull and body behind the sound source may be the major factor in the rearward and downward attenuation of the sound field. Further, we have the still unproved possibility that the fatty melon may function as an acoustic lens (Norris, *et al.*, 1961; Norris, 1964).

Our experience with the Vancouver *Orcinus* supports and somewhat extends these ideas. Perhaps the melon is dominant in focussing the sound transmissions, for the rather flat face of the *Orcinus* skull does not seem suitable for forming as sharp a high-frequency beam as we have observed. It is high time for some real acoustic measurements of this mass of nasal fat.

CHARACTERISTICS OF *Orcinus* PHONATION

We have alluded to some conspicuous differ-

ences between the phonation of the single captive *Orcinus orca* in Vancouver and that of its relatives, the smaller delphinids.

1. The whistle-like squeal of the smaller delphinids, which they appear to use for communication, was never heard from the Vancouver captive. We have not recognized it in the other recordings of *Orcinus*. The U. S. Navy recording of October 20, 1960, in Dabob Bay, includes a very few squeals, but it is not certain what made them (this record also includes a few human whistles made over an underwater transmitter). It is possible that these squeals were made by some unseen delphinid, perhaps at a considerable distance. It is also conceivable that they were made by some of the small calves in that group of *Orcinus*, but we have yet no other hint that *Orcinus* baby-talk may include squeals, except perhaps Grieg's (1907) "fluting sound."

Further evidence that squeals are not part of the *Orcinus* repertory is the use of the screams (markedly pulsed calls) when one would have expected a small delphinid to squeal. When our captive screamed, it was apparently trying to communicate (stimulated by outside disturbance, usually a passing boat). The screams were much louder than the clicks, just as, at sea, the communicative squeals of delphinids are ordinarily heard further than their clicks.

2. *Orcinus* clicks are unlike those of any other delphinid known to us and are distinguished by their emphasis of discrete fundamental frequencies. They are narrow-band and low frequency; typical delphinid clicks are broad-band, though there may be some local emphasis at certain frequencies. Valdez (1961) evidently noted this marked difference in pitch when he rendered the clicks of his *Lagenorhynchus* "hîn, hîn, hîn" and those of *Orcinus* "hün, hün, hün;" he also noted that (as may be seen in his figures) the former are very much shorter than the latter. His estimates of signal lengths of less than .5 m and 1 to 2 m, respectively, are, considering the difficulty of making sharp measurements on an echo-sounder record, consonant with our own timing of 2 to 3 msec and 10 to 25 msec.

There is some resemblance to the clicks of *Phocoena phocoena* (Linné) 1758, which, as shown by Busnel, Dziedzic & Andersen (1963) and in recordings by Carleton Ray from New Brunswick (Passamaquoddy Bay), are also narrow-band and low frequency, but at about 2 kcps, which is markedly higher than *Orcinus*. *Phocoena* is not closely related to *Orcinus*; it is a member of a different family, Phocoenidae, which is plainly distinct morphologically. Incidentally, we have never heard a squeal from any phocoenid (we have listened to *Phocoena* and *Phocoenoides* at sea) nor have we heard of

one from others who have listened at sea or to captives.

Study of the recordings of groups of free *Orcinus* by others mentioned above encourages us to suppose that these differences are not peculiar to our one specimen, but are valid for the species.

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EXPLANATION OF FIGURES

FIGURE 1

A. An oscilloscope picture of one recorded click emitted by the *Orcinus* nearly head-on toward the hydrophone.

B. A click recorded less than 2 seconds later when the whale was nearer the hydrophone, but turned somewhat away from it. Note the high amplitude high-frequency components of the beginning of the pulse in A and the higher amplitude low frequencies in B. The grid divisions are 2 milliseconds apart.

FIGURE 2

A typical scream of *Orcinus*. Note the clicks separated at the beginning and the two single-frequency sections of the call at 2,000 and 500 cps. The analyzing filter bandwidth is 200 cps.

FIGURE 3

A succession of *Orcinus* clicks produced as the animal turned a few degrees horizontally. During the first of these clicks the whale was coming nearly head on; note the progressive loss of high frequencies even though the animal was getting closer. Analyzing filter bandwidth is 400 cps.

FIGURE 4A

Orcinus clicks received as the animal was heading toward the hydrophone.

FIGURE 4B

As the whale went past. The high-frequency components have dropped out of the clicks, although the low frequencies are very much louder with proximity. B was about 1.5 seconds after A. Analyzing filter bandwidth is 400 cps.

FIGURE 5

A series of clicks produced by the *Orcinus* as it approached and passed the hydrophone. Note the single-frequency emphasis (fundamental) of the clicks, as well as the loss of the second harmonic as the whale comes alongside the hydrophone. The amplitude of the main lower frequency component of the clicks, however, increases with the whale's proximity. This time the animal passed a meter or so away and had not headed directly toward the hydrophone, so that only the lower frequencies show. The vertical line in the middle and the blobs at the bottom of the spectrogram are noise. Analyzing filter bandwidth is 60 cps.